Sagan Summer Workshop

Mission Group Project: Designing a Mission

TEAM X
Jet Propulsion Laboratory

Keith Warfield

Lead Concurrent Engineer – Team X

What Are the Pieces of the Puzzle

- **What do I want to do (Science Goals)?**
- **What Am I Going to do (Instrument + Telescope)?**
- **Where Am I Going (Orbit)?**
- **What do I put everything on (Spacecraft)?**
  - Slewing? Pointing? Data? Vibration? Power?
- **How do I get there (Launch Vehicle)?**
  - Where are you going? How much mass?
- **How much will it all cost?**
- **How soon can I have it?**

What Are My Goals

- Science matrix ties science goals to mission design requirements
- Objectives are set by NASA Astrophysics roadmap
- Science teams measurement objectives and translate those objectives into measurement requirements, instruments and mission requirements

Science Objectives	Measurement Objectives	Measurement Requirements	Instruments	Mission Requirements
Determine how planets form in dense disks of gas and dust around young stars				
Study the formation and evolution of planetary systems				
Explore the diversity of other worlds				
Search for habitable planets and life				

Instrument Design

- Astronomy missions are usually driven by the instrument and science requirements on the spacecraft
- Instrument design is done separately from the total mission design due to the complexity of the instrument design process

How Much Is That Telescope?

		Mass (kg)	Power (W)	Data rate (kbps)	Technology Development	Cost ($ FY09)
Instruments	Lyot Coronagraph	150	50	70		$ 70 M
	PIAA Coronagraph	170	65	70	Optics	$ 90 M
	Photometer	120	75	300		$ 60 M
	Interferometer	120	250	5		$ 70 M
	50k x 50k FPA Wide Field Survey Camera	350	200	400000	FPA's	$ 300 M
	2k x 2k camera	10	10	600		$ 20 M
	Vis Spectrometer	40	30	3000		$ 30 M
	IR Spectrometer	40	30	3000		$ 20 M
	UV Spectrometer	40	30	3000		$ 40 M
Telescopes	0.5m Telescope	30	25	n/a		$ 20 M
	1.0m Telescope	150	75	n/a		$ 50 M
	1.5m Telescope	300	225	n/a		$ 150 M
	2.0m Telescope	700	300	n/a		$ 500 M
	4.0m Telescope	2000	400	n/a	Large optics, I & T	$ 1500 M

Telescope Adjustments:

1. Add 50% to cost for off axis
2. Add 30% to cost for UV
3. Subtract 30% from cost for IR only
4. Add 50% for passive cooling (45 K)
5. Add 50% for active (He) cooling (4 K)

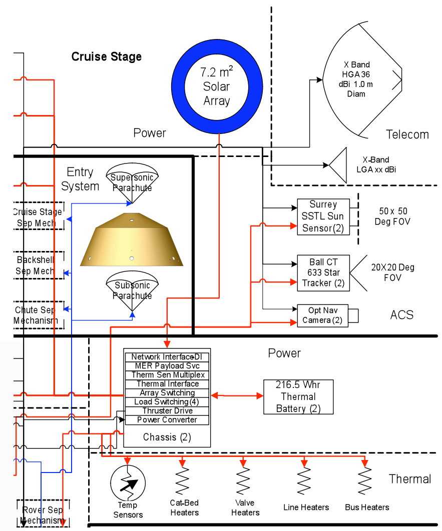
Instrument Adjustments

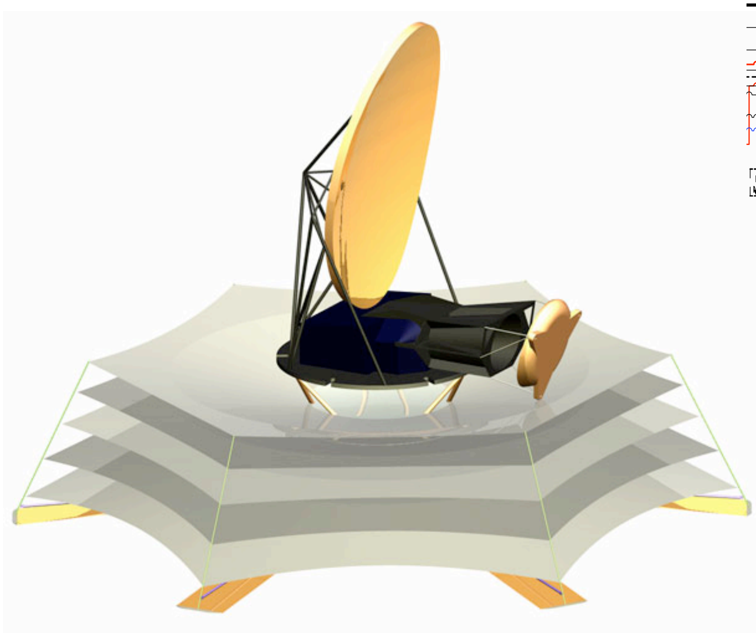
1. Cryocooler or dewar add $50M

Spacecraft Design

Key Trades

- Information System
- Power
- Propellant/Structure/Mass
- Pointing
- Cost





Pointing Trades

- Pointing control – the ability to point the instrument payload at a specific target within a given accuracy.
- Pointing knowledge – the after-the-fact reconstruction of the true instrument position within a given accuracy.
- Pointing stability – holding a position within a tolerance for a fixed period of time (integration time).
- Slew rate – Slewing can be a significant period of the total mission life. Reaction wheels must be large enough to achieve the required rate.

	Pointing Control	Stability
HST	0.01 asec	0.007 asec/24 hours
Spitzer	0.5 asec	0.1 asec/200 sec
WISE	60 asec	1 asec/9 sec

Where Is My Data?

- **Daily data volume**
  - Instrument data rate x operation/day
  - Size of array, number of arrays, integration time, etc.
- **Assume x2 lossless compression, 4 bytes=32 bits/pixel. Add 10% overhead**
- **Link time is expensive. Ka band is expensive.**
- **Taking data while observing requires (expensive) steerable antenna**
  - Spitzer downlinks (once/1 day for 2 hours) and Kepler (once / 2-4 days)

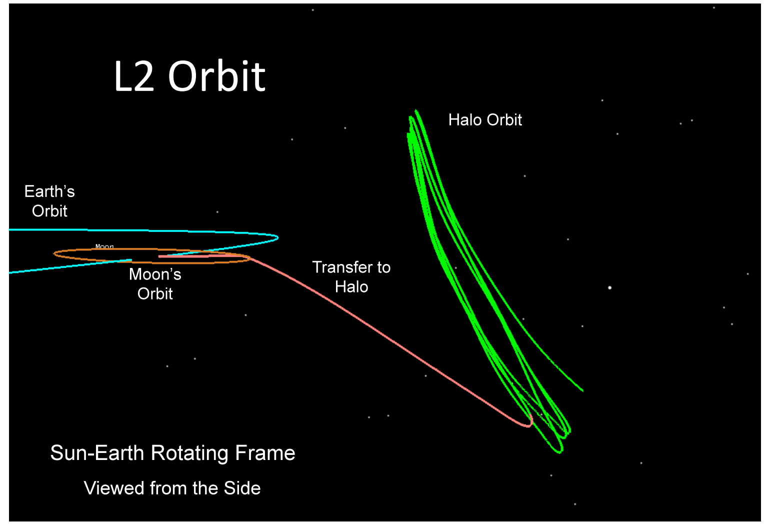
	Low Earth Orbit	**L2**	**Earth Trailing**
Telecom rate Mbits/sec	320,000 (X band)	300 (X) 320,000 (Ka)	3/yr^2 (X) 3200/yr^2 (Ka)
Connect time	8min/orbit; 90 minute orbits	8 hrs/day	8 hrs/day

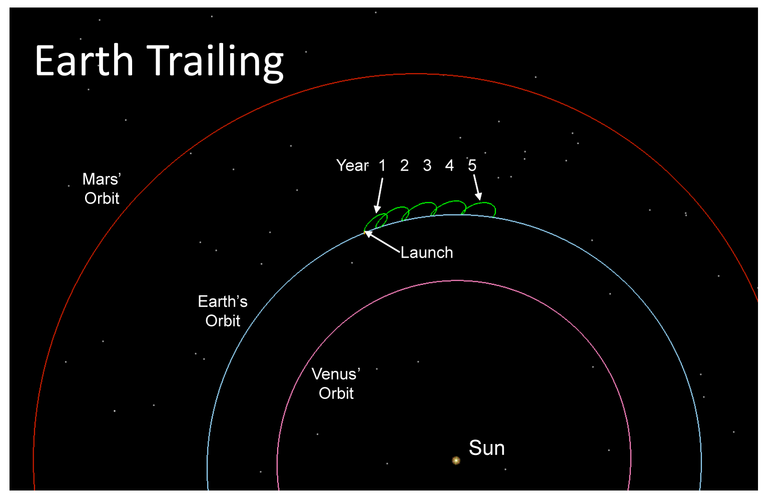
What Is a Spacecraft?

		Spacecraft A	Spacecraft B	Spacecraft C	Spacecraft D
Payload Power	W (EOL)	50	66	730	650
Payload Mass Limit	kg	70	200	380	650
Bus Dry mass (w/o Payload)	kg	60	125	600	350
Science Data Downlink capacity	kbps	2000	2500	320000	80,000
Science Data Storage capability	Mbit	3	2000	134000	100,000
Pointing Knowledge	arcsec	2880	3	3	0.5
Pointing Control	arcsec	2160	32	5	16
Pointing Stability (Jitter)	arcsec/sec	36	0.1	0.05	0.1
Slewrate	deg/min	60	390	240	120
Mission Design Life	yrs	1	2	5	5
Cost	$ FY09	$ 50 M	$ 75 M	$ 125 M	$ 150 M

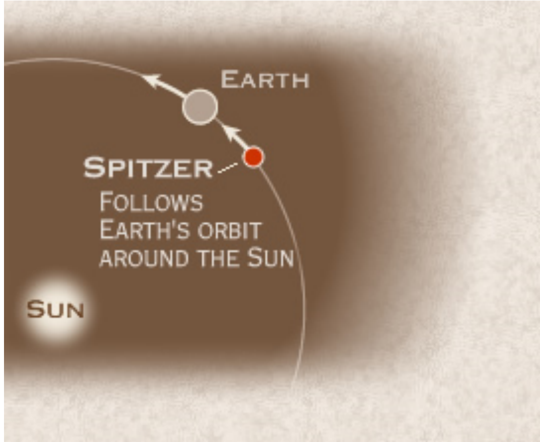
Orbit Selection

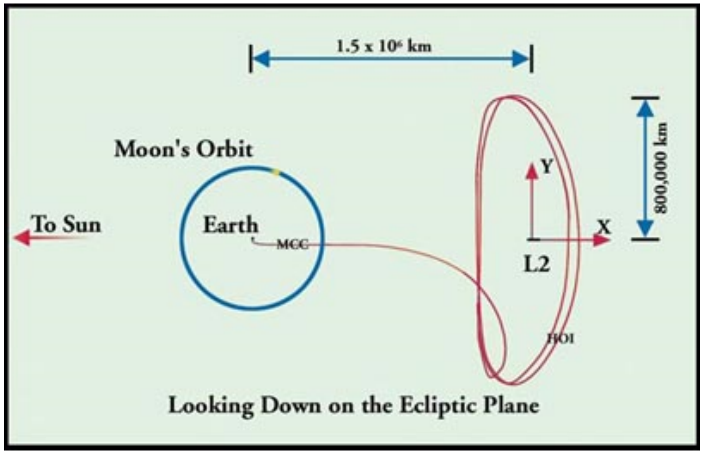
- Trading telecom needs vs. station keeping requirements vs. launch vehicle costs vs. eclipse and downlink opportunity issues vs. mission duration
- Trades usually require complete design of the spacecraft and mission to evaluate
- All subsystems can be impacted by the decision
- Spacecraft design and launch vehicle selection are similar for L2 and Earth trailing





Where Is My Spacecraft?





	Low Earth Orbit (Eq)	Low Earth Orbit (Polar)	L2	Earth Trailing
Launch Vehicle	Inexpensive	Modest	Expensive	Expensive
Thermal	Complex, hot Earth, eclipses	Stable hot Earth	Stable, cold	Stable, cold
View of Sky	Earth and Moon avoidance	Good along terminator or anti-sun	Excellent. Constant geometry	Excellent. Constant geometry
Data Rates	Easy, high	Easy, high	Moderate	Expensive with time
Propulsion	De-orbit	De-orbit	L2 Entry, station keeping	None

Launch Vehicle Capabilities

	600 km Polar Orbit	L2	Earth Trailing	Cost
L/V A	800 kg	N/A	N/A	$57M
L/V B	6,800 kg	3,495 kg	3,485 kg	$136M
L/V C	20,790kg	9,410 kg	9,395 kg	$220M

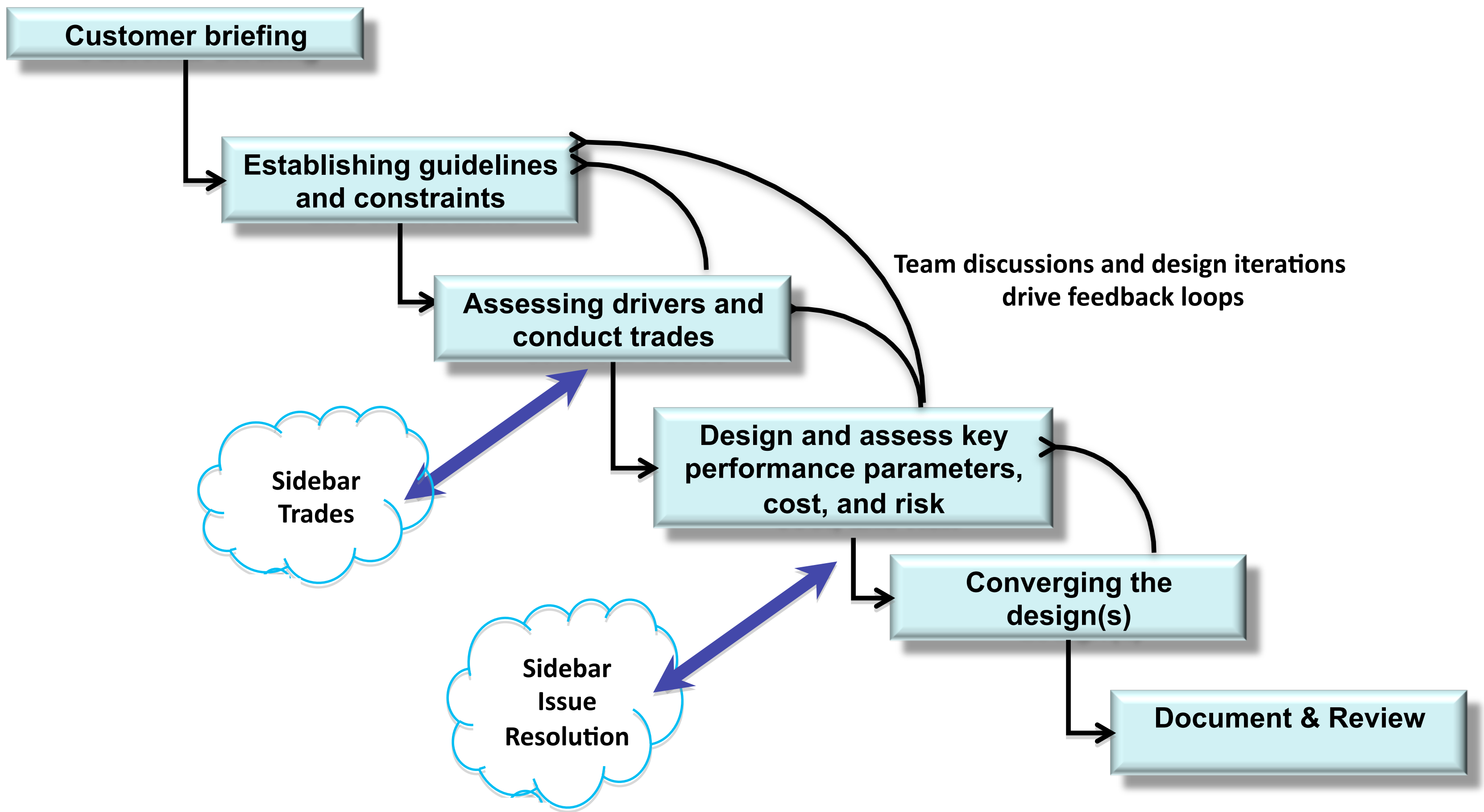
How Expensive Will It All Be?

COST SUMMARY (FY2009 $M)		
WBS Elements	**Total**	
Project Cost ($ FY09)	**$514.1 M**	
Development Cost (Phases A - D)	**$396.8 M**	
01.0 Project Management	**$15.3 M**	5% of development
02.0 Project Systems Engineering	**$15.3 M**	5% of development
03.0 Mission Assurance	**$12.2 M**	4% of development
04.0 Science	**$10.0 M**	
05.0 Payload System	**$100.0 M**	
Instrument 1	**$100.0 M**	
Instrument 2		
Instrument 3		
Instrument 4		
Instrument 5		
06.0 Flight System	**$100.0 M**	
07.0 Mission Operations Preparation	**$15.0 M**	$15M
09.0 Ground Data Systems	**$15.0 M**	$15M
10.0 ATLO	**$14.0 M**	7% of Payload and Flight System
11.0 Education and Public Outreach	**$1.5 M**	0.5% of development
12.0 Mission and Navigation Design	**$7.0 M**	$7M
Development Reserves	**$91.6 M**	30%
Operations Cost (Phases E - F)	**$17.3 M**	
Operations	**$15.0 M**	$15M/yr years
Operations Reserves	**$2.3 M**	15%
8.0 Launch Vehicle	**$100.0 M**	

What Are My Opportunities?

Class	Total Cost Limit	Comments	
Small Explorer	$105M	Highly focused. Single instrument. No technology. No risk. NuStar, Galex. 2-3/decade	
Medium Explorer	$300M	Highly focused, Single instrument. No technology. No risk. WISE	
Discovery Class	$500M	Kepler. Not available to astronomy	
ExoPlanet Probe	$650-800 M	Sophisticated instrument. Broad appeal. GO program. Modest technology? 1-2/decade?	
Major Observatory	$1,000-2,000M	Spitzer, Chandra. Sophisticated instrument(s). Broad appeal. Strong GO/GTO. 1/decade	
Mega Flagship	>$5,000M	HST, JWST. 1/generation. Numerous complex instruments. Very high technology risk. Should feed many astronomers through GO programs	

Design iteration and convergence



- Design process is <u>non-linear</u>
- Design issues delegated and resolved simultaneously
- Sidebar discussions initiated as needed

Outline

1. Science goals, mission name (bonus for acronym and logo!!)
2. Define telescope and instrument
3. Choose orbit
4. Calculate data volume, rate and downlink
5. Calculate pointing requirements
6. Select spacecraft bus
7. Determine launch mass
8. Select launch vehicle
9. Describe major risks
10. Estimate total mission cost

1. Science goals

- Major science goals and relevance to field
- Mission name (and acronym/logo)

2. Define telescope and instrument

- Wavelength
- Size
- Sensitivity
- Resolution (spectral and angular)
- Thermal Requirements
- Duration

3. Choose orbit

- **Consider data rate, background noise, launch cost**

4. Calculate data volume and rate

- Calculate data volume and rate
- Is this consistent with orbit and downlink capabilities?

5. Calculate pointing requirements

- **Use the least stringent pointing needed to accomplish the science**

6. Select spacecraft bus

- Depends on size of instrument, telecom capability, pointing capability

7. Determine launch mass

- Telescope
- Bus
- Instrument
- Propellant
- Margin

8. Select launch vehicle

- Mass
- Orbit
- Cost

9. Describe major risks

- Unusual size
- New technologies
- Below guideline margins

10. Estimate total mission cost

- Telescope
- Bus
- Instrument
- Launch vehicle
- Operations
- Reserves